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Irrigated Agriculture and Environmental Pollution

Lessons from the Westside San Joaquin Valley, California

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Abstract

This report focuses on agricultural drainage and salinity problems associated with irrigated agriculture in the Central Valley of California. The development of irrigated agriculture in that region is described, along with the evolution of the drainage-salinity problems. Studies estimating the economic value of the damages and the social costs of solutions to the problems are discussed and compared. Physical, institutional, legal, and economic aspects are highlighted. Policy solutions need to take into account the complexity of the problem and the inability of a single measure to provide a comprehensive solution.

Keywords: Salinity, drainage, selenium, San Joaquin Valley, irrigation

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Introduction

The water outlook in the United States has both quantity and quality aspects. While the quantity aspect is relatively easy to address, water quality problems in many locations are difficult to identify, measure, and control.

Estimates as early as in Landsberg (1964) suggest great differences in available water quantities, and in the ratio of water consumed to water available, between the Eastern and Western United States. In the Eastern United States, the amounts of water withdrawn and consumed are extremely small compared with the water available. By the year 2000, projected depletion would amount to less than 5 percent of the maximum flow. In the Western United States, most of which is arid or semiarid, the problems are extremely different. A large proportion of the West's water supply, which is about one-fifth that of the East, is used for agricultural irrigation. As a result, in 1960 the estimated total depletion in the West was four times what it was in the East, and is expected to amount to 60 percent of the maximum flow by the year 2000. Therefore, water policies should (a) address differently Eastern and Western water problems, and (b) agriculture, as a major water user in the West, should receive special attention in planning and resource allocation.

Agricultural activity contributes also to environmental quality problems, with residuals of pesticides and fertilizers used in the production process entering surface and ground water. In addition, the irrigation process in certain locations is associated with soil erosion, sedimentation, and drainage waterlogging problems. Reichelderfer and Phipps (1988) stated that 70 percent of the nutrients and 33 percent of the sediments reaching waterways originated on agricultural land.

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In certain locations, irrigated agriculture may be associated with drainage problems that are the result of the soil's limited ability to get rid of excess water to groundwater aquifers. This waterlogging of agricultural soil causes losses to agricultural producers and an accumulation of toxic elements in the soil, which is another aspect of water quality problems.

Irrigated agriculture on lands with poor natural drainage requires artificial means for disposing of agricultural water applied in excess of plant needs. For example, in 1985 about 107,483,000 acres, or 5 percent of total U.S. land and 24 percent of cropland, were drained artificially, of which about 65.2 million acres were equipped with surface drains and about 44.8 million acres with subsurface drains (Pavelis, 1987).

Agricultural drainage is associated with high direct investment costs and direct and indirect third-party-effect costs (quantity and quality). The accumulated total investment in drainage since 1855 was $56 billion (in 1985 dollars) and the combined net value of all drainage assets in agriculture in 1985 was about $25 billion, while the total capital value of all U.S. farm real estate was equal to $690 billion (Pavelis, 1987).

Agricultural drainage pollution is an externality affecting agricultural production (the down slope effect) and environmental amenities (disposal of the drainage toxics). Adding the costs of third-party effects associated with drainage (which is quantitatively more difficult to measure) via policies directed at internalizing these effects suggests that drainage is a significant factor in agricultural decisionmaking in many locations.

Wetlands are a major environmental amenity and are affected by water quantity/quality problems. Historically, wetlands were thought to be of relatively low value. In the 19th century, for example, Federal policies actively encouraged landowners to convert wetlands to more useful purposes. As scientists identified the valuable ecological functions performed by wetlands, however, public pressure arose to protect the remaining wetlands. The country now has about 100 million acres of wetlands, slightly less than half the amount that existed 200 years ago (Zinn, 1991).

It is now recognized that wetlands have many uses, some being wildlife habitat, flood storage areas, groundwater recharge areas, siltation basins, ecological filters, and recreation and educational facilities. These services of wetland areas can be assigned dollar values like any economic activity. Agriculture competes with wetlands for scarce land and water resources and uses wetlands to drain excess irrigation water, often carrying toxic agricultural residuals. In recent years, as lifestyles have changed, individuals have put higher values on the environmental services that wetlands provide (Swader and Pavelis, 1987). As a result, there are continuous pressures to allocate more resources toward preventing wetlands conversion and damage from agricultural water quantity/quality problems.

This report is concerned with one aspect of the agricultural water quantity/quality problem in one location--the drainage problem in the San Joaquin Valley of California. The report summarizes up-to-date physical, economic, and policy-oriented studies associated with this problem and discusses consequences of their implementation.

The Problem of Irrigated Agriculture in the San Joaquin Valley

The San Joaquin Valley: Development and Water Quality

In 1992, California entered its sixth straight year of continuing drought—the longest dry period in nearly 100 years of recordkeeping. The San Joaquin Valley, the State's largest and most productive agricultural region, also experienced water-quality problems, both prior to and during the drought, that have been related to extensive irrigated agricultural activity in the region. Wetland areas in the San Joaquin Valley were also affected by agricultural expansion in the last decade. It is estimated that public and private wetlands have been reduced by over 50 percent during this period to its current area of 190,000 acres (SJVDP, 1989). In this section, the San Joaquin Valley case study will be introduced to the reader.

Natural History and Hydrogeologic Setting

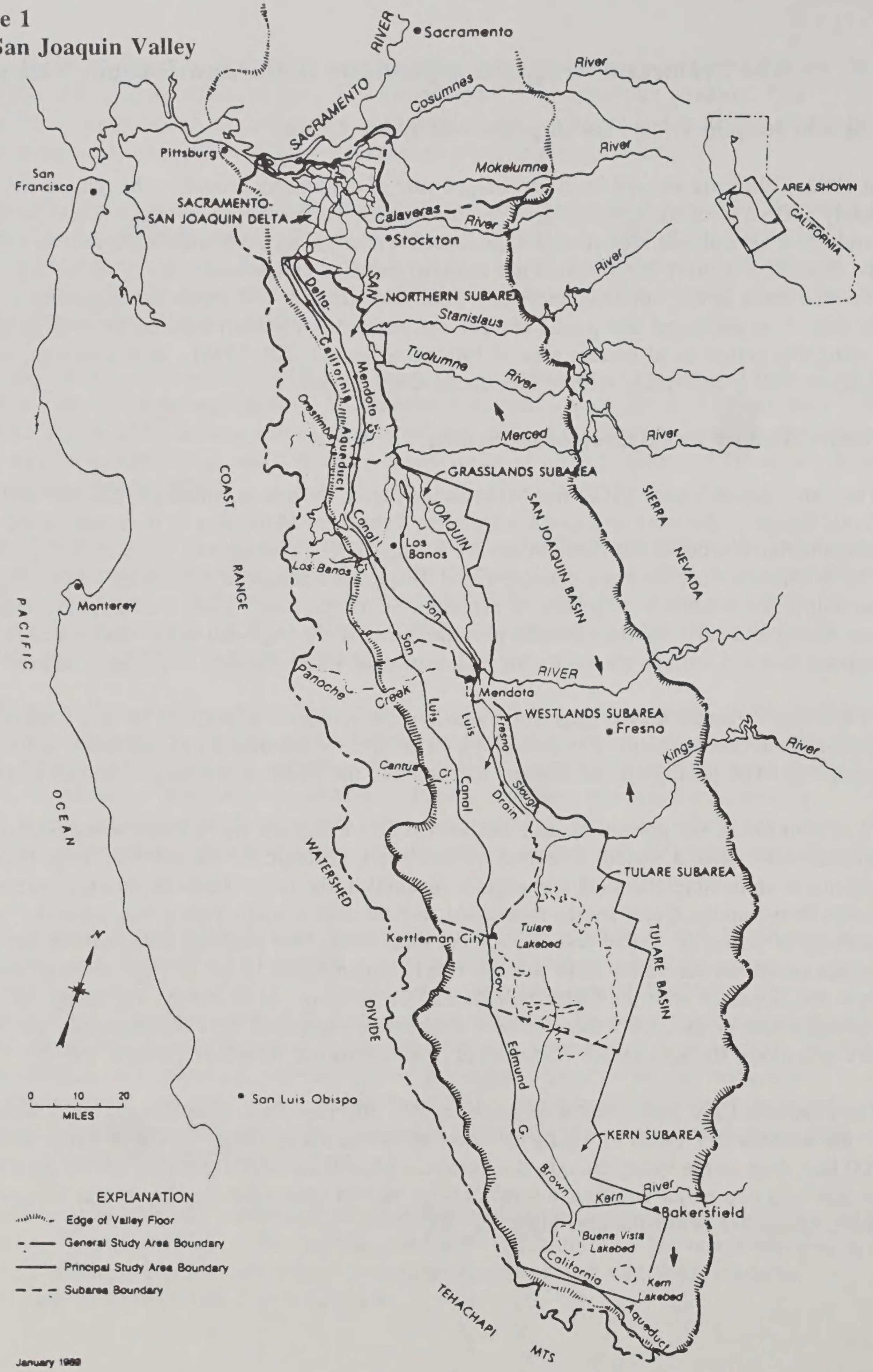
The San Joaquin Valley (SJV) lies between the Sierra Nevada mountains to the east and the Coast Range to the west, and extends from the Tehachapi Mountains to the south to the San Joaquin–Sacramento River Delta to the north (fig. 1). The climate and hydrologic cycle in the SJV is characterized by a dry summer (90–110 degrees Fahrenheit on average) and low, unstable rainfall in the winter (5–10 inches on average). Snowmelt runoff from the Sierra Nevada in the late spring and early summer months provides most of the imported water, and necessitates impoundment in storage reservoirs for reallocation of water during the irrigation season.

Two critical factors set the stage for water-induced problems in parts of the SJV: hydrology and geologic soil composition. The hydrology factor sets the location and availability of water resources. The geology factor sets the location and the extent of the water-induced problems.

In ancient times, the portion of land west of the Sierra Nevada was a shallow-water coastal marine basin. Over a period of several million years, geologic forces deposited huge quantities of sediments containing chemical and organic material in the basin. Later in geologic history, these forces thrust up the Coast Range mountains, and the San Joaquin Valley was created. For many millions of years, the valley was like a great inland sea. Tiny particles suspended in the marine waters settled on the valley floor to form nearly impermeable layers of clay. Material eroding from the slopes of both the Sierra Nevada and Coast Range deposited on the valley floor. The alluvial plains created from these erosion deposits converged at the valley's trough, giving today's SJV a smooth, flat appearance (Letey et al., 1986; National Research Council, 1989).

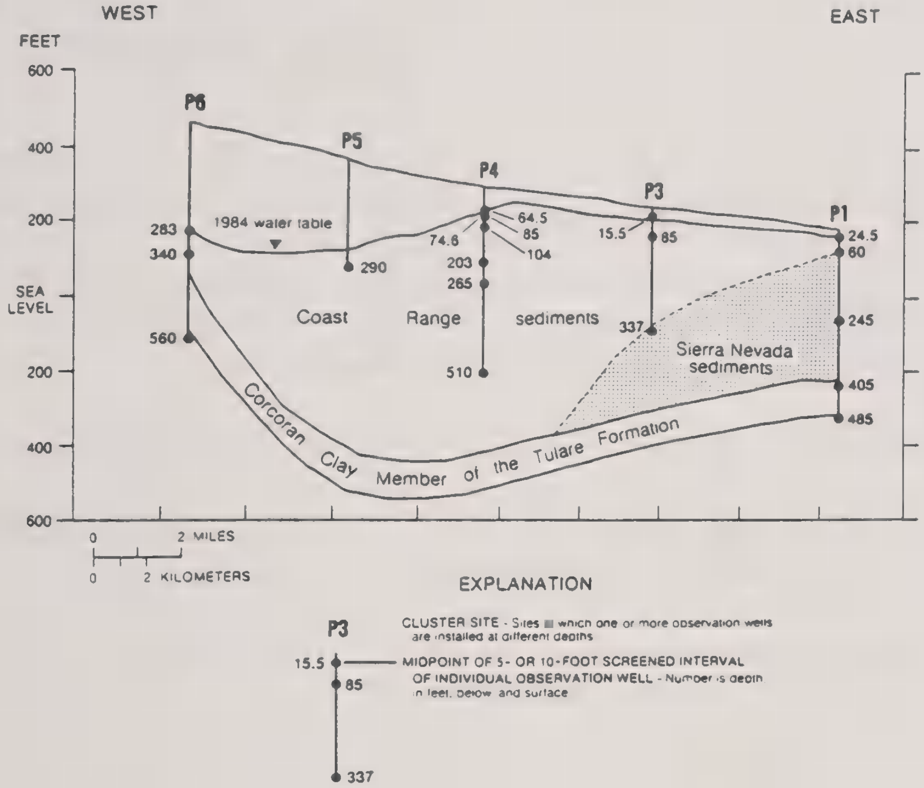
The Corcoran Clay layer, which ranges from 20 - 200 feet thick, underlies all but a small portion of the western SJV (WSJV). Lying as much as 850 feet deep along the Coast Range and 200 - 500 feet deep in the valley trough, the Corcoran Clay layer effectively divides the groundwater system into two major aquifers: a semiconfined aquifer above the clay layer, and a deeper, confined aquifer below the clay layer (fig. 2).

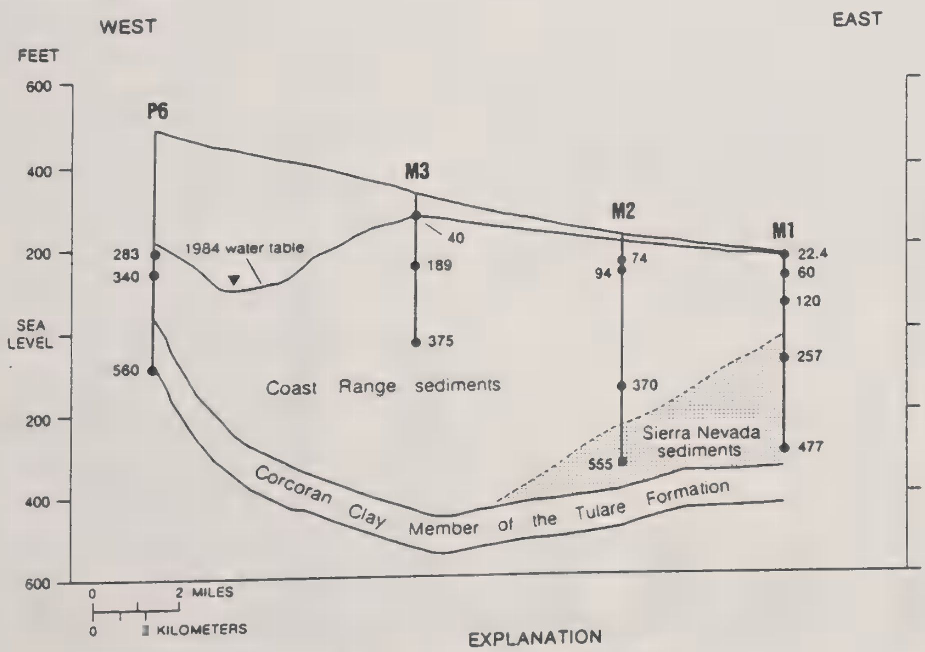
Figure 1
The San Joaquin Valley

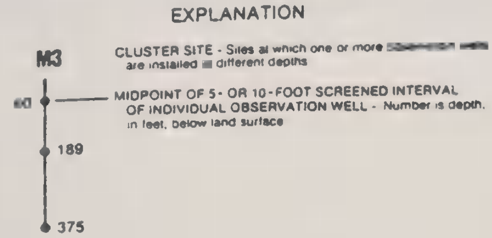


Source: San Joaquin Valley Drainage Program (SJVDP, 1990).

Figure 2
Geohydrologic Cross-Sections of the San Joaquin and Tulare Basins







Source: Gilliom (1991).

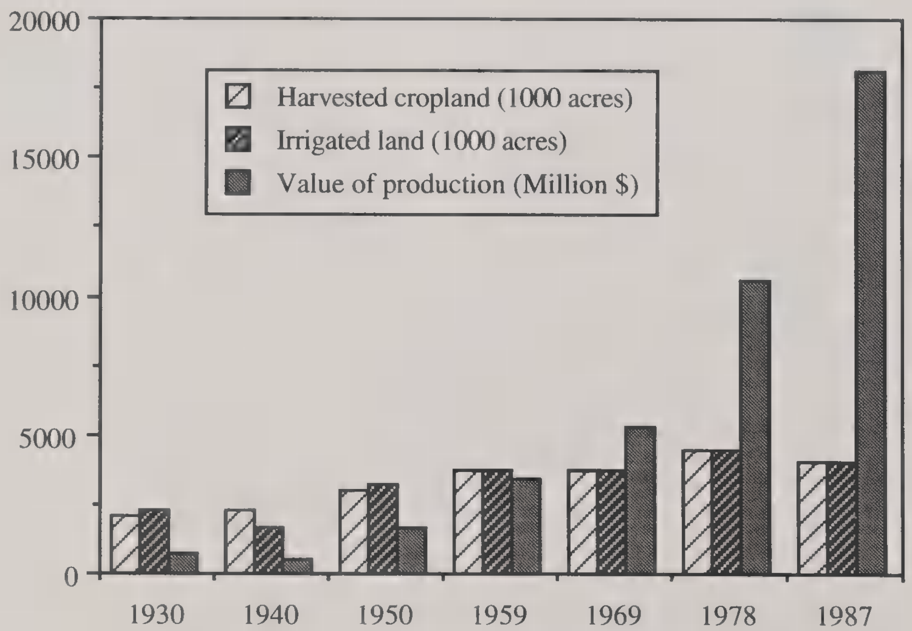
SJV Irrigation Development and Water Quality Problems

The development of the San Joaquin Valley is tied to water availability.[2] The irrigation history of the SJV includes several stages, starting as early as 1839 (Mercer and Morgan, 1991). Since the turn of the century, the SJV has experienced a steady growth in irrigated agriculture (fig. 3), accompanied with increased use of the valley's natural resources.

In 1935, the U.S. Congress authorized the Central Valley Project (CVP) to transfer water from northern California to the arid areas of the SJV. The initial features of the project were completed in the 1940s and the first water was delivered in the early 1950s. Additional water facilities, such as the San Luis Unit, were authorized by 1960. During the 1920s, California developed the State Water Plan for additional transfer of water to the State Water Project (SWP). But not until 1968 did the SWP start delivering water to the SJV.

Until 1940, the total capacity of irrigation-water storage in the SJV was nearly 0.65 million acre-feet (maf) (fig. 4). In the mid-1940s, the completion of the CVP's Friant Dam nearly doubled the irrigation storage capacity. Major expansions in the late 1960s and 1970s brought irrigation storage capacity in the SJV to its current level of nearly 6.5 maf. The SWP provides irrigation water to lands in the southern part of the SJV, while the San Luis Unit provides CVP irrigation water to lands in the northwestern part of the valley.

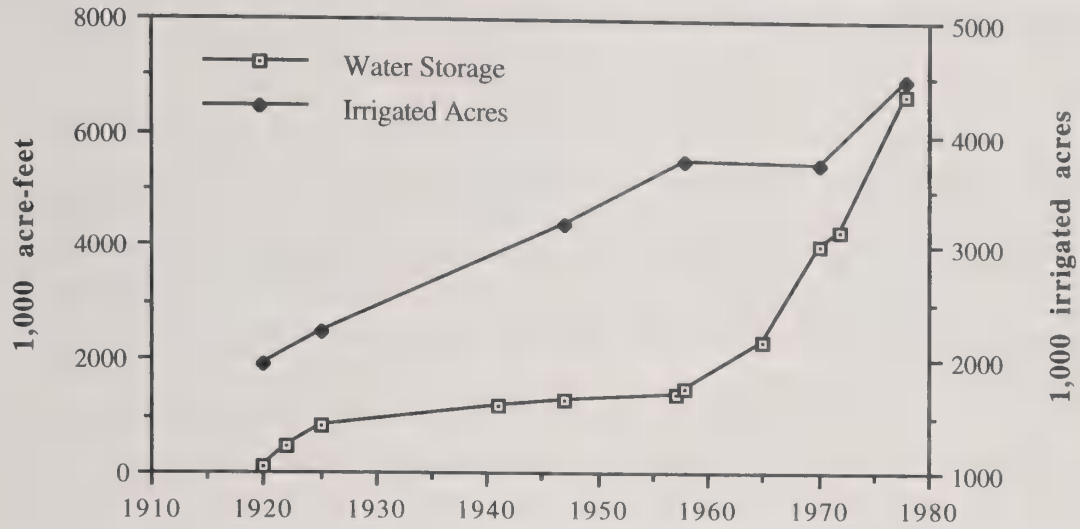
Figure 3
Changes in the Agricultural Resource Base and Production in the SJV from 1930 to 1987



Source: Compiled from Mercer and Morgan (1991).

[2]For a comprehensive review of Central Valley problems, see Moore and Howitt (1988).

Figure 4
Cumulative Project Water Storage and Irrigated Land in the SJV from 1920 to 1990



Sources: Modified from Mercer and Morgan (1991), and based on Orlob (1991).

The expansion of irrigated land in the SJV very closely follows the trend of available irrigation-water storage capacity (Mercer and Morgan, 1991). Moreover, the share of acreage of intensively irrigated crops such as cotton, vegetables, and orchards on the irrigated land rose dramatically, from 42 percent in 1950 to 64 percent in 1987.

Waterlogging and salinization of soil and shallow- and deep-water aquifers arose on the western SJV as a direct consequence of changes in the region's hydrologic system caused by the salt load of imported irrigation water.[3] The salinity and shallow groundwater problems may have been aggravated by the particular geologic setting of the region and the lithologic interactions with the irrigation water. Broader problems of basinwide salt balance became apparent in the 1950s. Declining water quality in the lower SJV was attributed to the replacement of native San Joaquin River water by imported water on a mass scale. Orlob (1991) estimated the net salt load accumulation in the SJV due to water importation between 1950 and 1989 at 18.6 million tons.

Imported water was used to irrigate some new lands, but it mainly replaced groundwater. The significant amounts of new water replenishing groundwater, coupled with the characteristics of the soil and geology in the region, caused the water table to rise slowly to near land surface in parts of the SJV. This clogged the soils and prevented adequate farming.

Plans for both the Federal and State water projects included a joint-use "master drain" to remove agricultural drainage collected under the lands of the western SJV. An 85-mile segment of the planned 210-mile, valleywide master drain was completed in 1975. Plans to complete the master drain were terminated due to budget problems. Kesterson Reservoir, a

[3]Drainage problems were reported as early as 1886 (Mercer and Morgan, 1991).

component of the master drain, was planned as a multipurpose facility that would serve as interim storage, as an evaporation and regulating pond, and as a wildlife habitat. Since the master drain was only partially completed, however, Kesterson became the terminal point for western SJV drainage.

In 1983, selenium contamination of wildlife at Kesterson was discovered and attributed to agricultural drainage disposed of there. This discovery placed the problem of irrigated agriculture in the SJV in the public forum. It also has broadened the analysis and discussion to include water quality rather than efficiency of water use in agricultural production alone. Very likely the San Joaquin Valley's problems with selenium would never have surfaced had there not been long-term irrigation development. Natural drainage from the valley was provided by the San Joaquin River system, and dissolved salts, including selenium[4], were transported by this system through the Delta and then to the ocean. Introduction of irrigation with water imported from outside the valley led to the need for additional drainage capacity. It also mobilized the salts and selenium stored in the soil profile.

Dimensions of the SJV Irrigated-Agricultural-Drainage Problem

Several studies have provided estimates of the severity of the drainage problem in the western SJV. The most up-to-date and comprehensive sources of information are the analyses of the San Joaquin Valley Drainage Program (1989 and 1990). This subsection is based on data from those reports.

The San Joaquin Valley Drainage Program (SJVDP) was initiated in 1986 by Federal and State agencies. The establishment of the project was in response to public concern about the water quality problems in the San Joaquin Valley of California. During its 5 years of existence, the SJVDP was involved in studying the scientific aspects of agricultural drainage-water contamination, and evaluated possible ways of reducing their contamination effects on human health, resource degradation, and agricultural productivity.

Of the 2.5 million acres of irrigable land in the western SJV, 2.3 million were actually irrigated in 1990 and 0.13 million were artificially drained. If no action is taken, it is expected that by the year 2000, 84,000 acres of agricultural land will have to be abandoned (SJVDP, 1990). This number is expected to reach 460,000 acres by the year 2040. Again if no action is taken, the estimated volume of surface drainage water is also expected to increase from 100,000 acre-feet in 1990 to 163,000 in the year 2000, and to 243,000 in the year 2040.

The analysis over the 50-year horizon (assuming all other variables are held constant) suggests the following scenario by the year 2040: (1) the total reduction in irrigable acres due to the drainage problem will reach 554,000 acres, (2) the total net present value of the accumulated loss of retail sales will be nearly $63 billion (in 1990 dollars), (3) the total net present value of accumulated losses of regional income will reach $123 billion, and (4) 9,200 jobs will be lost (SJVDP, 1990).

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[4]Salts and selenuim are naturally occuring in this region.

Organization and Institutional Structure of Irrigation Water Supply and Demand

To better understand potential difficulties of implementing any policy aimed at addressing SJV drainage problems, it is essential to be familiar with the existing water-related institutional structure in the San Joaquin Valley.[5]

The Constitution of the State of California provides that all water within the State is the property of the people of California. Although the physical resources remain a public asset, however, individuals may acquire exclusive rights to their use through property rights. Private rights are conferred to those who exercise physical control over surface- or groundwater sources. Two types of rights, appropriative and riparian, are administered through water permits.[6] The State Water Resources Control Board (SWRCB) is the agency that protects the State's water for the people of California and oversees the allocation of rights to these resources for "beneficial uses." Beneficial uses include irrigation, groundwater storage, and fish and wildlife uses.[7]

Surface-water supplies in the region are from the Federal and State water projects (CVP and SWP, respectively), from groundwater sources, and from local surface waters. The U.S. Bureau of Reclamation holds permits for the CVP water, and the California Department of Water Resources holds permits for the SWP water. The SWRCB controls the permit policies of the two water projects. Although no administered permit system exists for groundwater, State law authorizes the SWRCB to prevent unreasonable use of any surface and ground water by any end user or contractor to the CVP or SWP. In practice however, the SWRCB has never used this power to address drainage problems (SJVDP 1990).

The CVP and SWP (as water wholesalers) provide water to local water entities (water retailers) such as water agencies, water districts, irrigation districts, and other companies and authorities. The service contracts between the CVP and SWP and the water agencies impose repayment, place, and manner-of-use restrictions on the contractors. Water purchased through Federal (CVP) contracts, which are generally in effect for 40 years and then open to renewal, involves entitlement for a stated maximum firm supply of annual volume. Water is priced once for the entire contract period. Current prices, paid by local water entities, vary between \$3.50 and \$19.31 per acre-foot in SJV water districts (water district operational costs are borne by farmers in addition to the basic water cost). Water use is restricted to agriculture and cannot be transferred outside of the district's boundaries without the U.S. Bureau of Reclamation's approval. Water purchased through State (SWP) contracts, which are in effect

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[5]A detailed description and analysis can be found in Thomas and Leighton-Schwartz (1990).

[6]The appropriative right permits diversions of water from streams on the basis of "first come, first served" and "use it or lose it." The amounts of water initially used determine the user's future quota. The riparian right grants property owners whose land adjoins water the right to take water for his or her use, as long as enough is left for downstream users.

[7]The urban and industrial sectors are *a priori* assumed to be beneficial uses.

for 75 years, is provided through annual entitlements. Monthly deliveries to agriculture are limited to no more than 18 percent of the contractor's annual entitlement, while prices are calculated annually. In 1990, SWP water in the SJV ranged from $32 to $67 per acre-foot (SJVDP 1990). With both CVP and SWP water, contractors pay for their total annual entitlement whether it has been used or not.

Growers within a given water district or that are served by a given water agency have shares or entitlements to district or agency water. Growers pay for the water at a rate designed to defray the capital costs of the facilities, water-project contract charges, and administrative expenses. Several pricing schemes exist (flat, tiered, or lump sum), as well as some water-use rules, such as recycling. In general, farmers decide on the timing, amounts, and manner of application. Within a single water year, allocations to contractors are declared and orders by growers are requested. If a grower chooses not to use a full entitlement in one water year, the remaining water usually cannot be transferred for use by the grower in the following year, but is generally used by other farmers in the district.

The Production Process of Irrigated Agriculture in the Western San Joaquin Valley

The Agricultural Production Process as a Potential Cause of Pollution

Irrigated agricultural production on the western (Westside) San Joaquin Valley (WSJV), affected by the geologic and hydrologic factors previously described, results in problems associated with saline shallow groundwater. These problems require suitable management practices to sustain agricultural productivity while minimizing adverse environmental impacts. This section describes the agricultural production process under conditions of limited drainage and increased salinity problems, a situation existing in the WSJV. The discussion in this section is based on recent research findings in Letey et al. (1986), National Research Council (1989), SJVDP (1990), and Grismer and Gates (1991).

The salinization process of agricultural soils by irrigation water is influenced by several factors that exist at any agricultural site. First, some degree of dissolved salts is contained in all irrigation water. The salt concentration may vary considerably, however, according to the origin of the water. Second, due to geologic forces, soils in some locations have naturally elevated amounts of mineral salts. These salts, if not activated or transported by irrigation water, can remain in the soil with no effect on soil salinity in the root zone. Third, in the process of irrigation, some water evaporates from the soil surface, and much more is transpired by plants, which extract negligible amounts of salts from the soil solution during transpiration, concentrating salts in the soil profile. Fourth, in order to maintain soil productivity, irrigation water quantity in excess of evapotranspiration (evaporation plus transpiration) is applied, with the extra water percolating and leaching the salts below the root zone.

The mineral salts that have been dissolved in the irrigation water remain and accumulate in the root zone. If the salt concentration in the root zone increases too much, some agricultural plants may be unable to absorb the soil solution and may suffer. Also, soil properties may be affected and result in agricultural damage. Therefore, irrigated agriculture will always be in jeopardy unless sufficient quantities of water are applied to leach out the salts from the root zone.

Leaching, which is necessary to allow a salt-free root zone, transports the salts from the root zone to other media such as deep aquifers. If deep percolation of water from the root zone is limited by a relatively impermeable stratum, then water accumulates above the impermeable stratum and may rise over time. This process causes root-zone salinity and waterlogging when the water table rises close to the soil surface. This interferes with the oxygen supply to the crop roots, which in turn results in additional damage to crop yield.

With an impermeable clay layer existing in many locations in the WSJV, natural drainage is extremely limited. The excess water that originally was meant to leach salts must be artificially addressed in order to prevent waterlogging. Drainage water in the WSJV is intercepted (via tile drains beneath the root zone), disposed of, transported, treated, or reused. Once drainage water has been intercepted and disposed of, the problem has been redefined. It is no longer a private problem of salinity and waterlogging. It is also a social problem, with the potential for severe externalities, which involve the adverse effects of agricultural drainage on other irrigators, fish and wildlife, and nonagricultural sectors.

Drainage Water Disposal and Externalities

The leaching process removes excess water, salts, and other dissolved compounds (such as agricultural chemicals or minerals) residing in the root-zone solution. If drainage conditions are not limiting, these waters are naturally drained to lower aquifers, resulting in groundwater quality problems. Where drainage conditions are poor, water must be removed from the root zone if agricultural productivity is to be maintained. Removal of the drainage water from the root zone, however, creates new and severe water quality problems. The extent of these problems depends also on the site and intended use of the drainage water.

In the case of the WSJV, the drainage water contains not only salts and agricultural residuals, such as pesticides and fertilizers, but also dissolved trace elements such as selenium, boron, molybdenum, and others. A detailed description of the hazardous effects of each element in the drainage water in the WSJV on different segments of the environment can be found in Klasing (1991), Skorupa and Ohlendorf (1991), and Saiki et al. (1991).

In recent years, with California's growing population and increasing standard of living, competition over the quality and limited quantity of California's water involves several sectors of opposing interests. Three sectors have an interest in and are affected by the quality and available quantity of water: agriculture, fish and wildlife (the environment), and the urban sector (in terms of both quantity and public health concerns). Details can also be found in Klasing (1991), Skorupa and Ohlendorf (1991), and Saiki et al. (1991).

The nature of the water quantity problems is a reflection of growing urban needs and change in consumer preferences. Bruvold et al. (1982) estimated that between 1980 and 2020, the population of California will increase from 22.8 million to 34.8 million. During that period, daily urban use water is estimated to increase from 4.5 gallons per capita per day in 1980 to 6.8 gallons in 2020 due to increases in the standard of living. Although the population-trend numbers underestimated the population of California in 1991 (32 million according to the 1991 census), the main point here is that competition over water between urban and agricultural users will have a major impact on the quantity and quality aspects of water problems in California.

The nature of the drainage externality effects of water quantity and quality on these sectors and their considerations appear in SJVDP (1990, 1989) and in Swain (1990). Fish and wildlife externalities include habitat losses and population declines. Agricultural effects include yield declines, soil deterioration, increased production costs, and the well-being of the agricultural sector and secondary beneficiaries. Public-health considerations include the safety of food crops, fish and game consumption, foraging, drinking water, and farm labor.

Results of Recent Policy-Oriented Studies Applied to the Western San Joaquin Valley: Evaluation of Policy Measures and Solutions

The San Joaquin Valley Drainage Program (SJVDP) conducted several studies that provide estimates of the extent of possible damage to several economic sectors if no policy action is taken. These benchmark values were then used to compare social costs and benefits associated with different management options aimed at reducing water quality and quantity problems. Results from studies conducted by the SJVDP and others suggest that there are relatively high returns to some management options, such as water source control at the farm level, and negative or no returns to other options, such as drainage-water treatment. One major conclusion from these studies is that the technological solutions are still far behind and need additional testing.

Drainage-water reuse was also evaluated as a means for reducing drainage volumes at the farm level. Several studies suggest that drainage-water reuse has the potential to mitigate the quantity problem of drainage water and, if carefully done, has the ability to reduce the salinity and selenium content of disposed drainage water.

Water markets have been suggested as one way to efficiently allocate irrigation water among individuals facing differential access to water. The studies reviewed here also suggest that the establishment of water markets has the potential of reducing drainage generation and environmental contamination.

A central question of the drainage-water problem in the western San Joaquin Valley (WSJV) has been the value of environmental or nonmarketable water-related amenities such as recreation, fish and wildlife population, and human health. Measurements for these aspects are

complicated and sometimes indicate inconsistent behavior in study results. The studies reported here suggest that relatively high values attached to environmental amenities, if included in any public policy analysis, would justify a high social investment to solve drainage-water problems. However, criticisms of both the approach and the results should be taken into account when these studies' results are considered for implementation.

Several studies reviewed in this section, when applied on a regional scale, suggest consideration of various regulations to control drainage. Among the policy options evaluated are taxes and quotas on surface and drainage water, and standards on drainage pollution. Among the several overall conclusions from these studies are: (1) a combination of policy instruments may be more successful than a single instrument; (2) since physical heterogeneity in the region affects the dimensions of the problem and the interrelations among the parties involved, different policies may be needed under different distributions of physical characteristics.

The San Joaquin Valley Drainage Program (SJVDP) analysis (1990) is probably the most comprehensive approach to the problem. The approach taken by the SJVDP was to minimize drainage-reduction costs while meeting future quantity requirements and quality standards. The analysis assumed various drainage-water quality zones within each subregion of the Western San Joaquin Valley (WSJV) study area.

The SJVDP-recommended management plan (applied to each water-quality zone) encompasses several components, as follows:[8]

- ***Source control at farm level:*** water conservation, drainage management, crop management, and alternate land use.
- ***Drainage water reuse:*** reuse on salt-tolerant crops (or during growth stages when crops are not sensitive), reuse for agroforestry (e.g., eucalyptus, salt bushes), and reuse for power plants.
- ***Drainage-water treatment:*** biological processes (e.g., anaerobic bacterial) and physical-chemical processes (e.g., adsorption using iron filing or iron oxides, ion exchange, and cogeneration).
- ***Drainage water disposal:*** out-of-valley disposal (e.g., to the east side of the SJV, the Mojave Desert, or the Sacramento–San Joaquin River Delta near Stockton), evaporation ponds, and deep-well injections to saline geologic formations.
- ***Land retirement.***
- ***Ground water management:*** pumping from beneath the Corcoran Clay layer, and pumping shallow water from above the Corcoran Clay.
- ***Fish and wildlife measures:*** protection of populations, restoration of habitat, and provision of substitute water supplies.
- ***Institutional changes:*** increased water prices; changes in water-price structure; water markets; reallocation of water among agriculture, urban, and environmental uses; payments only for water used; subsidies for investment in water conservation; constraints

[8]For detailed information, see SJVDP (1989, 1990) and Swain (1990).

and fees on drainage disposal; regional approaches to drainage problems; and federally funded programs for land retirement.

The estimated annualized costs associated with the SJVDP-recommended plan is $42 million for the next 50 years. To evaluate this figure, one must compare it with potential losses should no policy action be taken. However, the SJVDP study does not provide detailed information for such comparisons. Some of the potential benefits and losses are difficult to estimate, and some may vary based on specific assumptions used.

Figures used in the 1990 SJVDP report apply only to the agricultural sector. These illustrations suggest that if no policy action is taken, the annual loss of crop value due to reduced yields and less productive lands is $440 million, that negative impacts on retail sales in surrounding communities would be about $63 million annually, and that personal income would be reduced by $123 million annually. Benefits from improved (or prevention of the degradation of) fish and wildlife resources, water and land resources, and public health effects were only qualitatively evaluated. Even with only the agricultural benefits included in the analysis, the SJVDP-recommended plan as a whole shows a relatively high benefit/cost ratio (14.9). This high number is probably suspect and will be questioned by many.

A recent report by the United States Department of the Interior (USDI, 1991) analyzed the economic and environmental impacts of plans for San Luis Unit drainage water. The San Luis Unit is made up of about 600,000 acres of agricultural lands, of which about 50 percent have shallow ground water. The USDI study was a response to the December 30, 1986, U.S. District Court order following the consolidation of two cases: the *Barcellos and Wolfson Inc. v. Westlands Water District* and the *Westlands Water District v. United States of America* . The study followed similar patterns as those of the SJVDP (1990) and evaluated similar alternatives, including two—ocean disposal and Delta disposal—that were not considered in the SJVDP (1990) report. Although the two alternatives were found to be complete and effective (USDI 1991), the social and environmental opposition to the alternatives precluded further consideration at the time the draft report was released.

Both studies are comprehensive in nature. They included a variety of alternatives to be considered. The remainder of this section attempts to summarize a variety of other studies that have dealt, using different approaches, with a subset of alternative arrangements to the drainage problem in the WSJV. We will categorize these studies using the list of management options suggested in the SJVDP study, although the subjects of some studies may fall under more than one category.

Source Control at the Farm Level

Grismer and Gates (1991) present a comprehensive long-term simulation model that accounts for major processes (including their stochastic nature) governing a shallow saline water table and their effects on water-table depth, salinity, crop yield, and net farm income. The analysis accounts for stochastic elements in the physical system and evaluates the stability of solutions provided by different management policies. The study concludes that it is important to simultaneously plan for irrigation and drainage, and to consider regional plans rather than

local ones. The results were sensitive to uncertainty in water-application rates and soil properties, and insensitive to uncertainty in drainage-disposal costs. An interesting result is that a regional optimal irrigation-drainage management practice for cotton under saline soils affected with shallow ground water is achieved with irrigation systems ranging between 75 and 80 percent efficiencies. Grismer and Gates argue that these efficiencies are in the available range for surface irrigation and, therefore, the investment in expensive pressurized irrigation systems should be carefully examined.

Moore and Dinar (1992) apply a multioutput-production-function approach in a longrun setting to data from the WSJV (reported in Dinar and Campbell, 1990). The main finding in Moore and Dinar (1992) is that producers in that region are in longrun equilibrium in land, yet surface water is a quantity-rationed input. This implies that a marginal change in water price to producers will not induce any significant water conservation on their part. Additional results suggest, in the case of cotton, that water-quantity reduction policies would have the greatest effect on water and land allocated to cotton production. Table 1 depicts water and land demand elasticities with respect to a water constraint for the crop types included in the analysis.

The response of cotton is very elastic as compared with all other crop types, which respond with an inelastic decline. Cotton acreage in this region is significant. In 1987, Central Valley Project (CVP) cotton acreage was 532,637 acres (5.4 percent of the Nation's cotton acreage). Therefore, a 10-percent surface-water reduction to cotton production is predicted to result in a decline of about 105,000 acres in cotton area. Multiplier effects of this policy can also be calculated (see Horner et al., 1991; Berck, Robinson, and Goldman, 1991).

Although designed to evaluate water-supply policies for the CVP, the results can also be interpreted in connection with the drainage problem in that region. The key question is, what will be the fate of the water released? If agricultural water supplies are reduced in the region, then a reduction in drainage is expected. Rough calculations suggest that 105,000 acres of cotton in the drainage problem area produce nearly 75,000 acre-feet of drainage water. Consideration of production and secondary-economic losses from land forgone, versus damage from drainage, should be incorporated in the analysis to evaluate policy implications.

Table 1 -- Land and water elasticities with respect to a water constraint

Item	Cotton	Field crops	Forage crops	Vegetables
Land demand elasticity	2.01	0.71	0.31	0.49
Water allocation elasticity	2.01	0.66	0.35	0.61

Source: Moore and Dinar (1992).

The study by Moore and Dinar (1992) dealt with the aspect of surface-water cost and availability on demand for land and water in the cases of several key crops in the WSJV. A study by Dinar, Campbell, and Zilberman (1992), which used the same set of data, investigated the likely effects on agricultural producers in the WSJV of adopting improved irrigation and drainage-reduction technologies. Among other variables included in this analysis were surface-water price and quota to producers. Here also, groundwater (where available) cost was included as an explanatory variable (in farm-level analyses, groundwater was included as a separate variable, while in field-level analyses, the cost of water was calculated) in addition to surface-water cost and quotas. In addition to original findings related to effects of environmental conditions on adoption, the results confirmed findings in previous onfarm technology adoption studies that, as the relevant resource becomes scarce, producers are more likely to adopt such technologies that compensate resource scarcity. Table 2 provides weighted aggregate elasticities for the share of modern technologies at either the farm or field levels for key explanatory variables.

The results in tables 1 and 2 (with regard to a surface-water quota) can be compared for their effect on water saving. In Moore and Dinar (1992) elasticity values vary from 0.35 to 2.01 for different crops, and in Dinar et al. (1992) values range from -0.036 to -0.27. One should remember that in Dinar et al., the estimated elasticities express changes in technology adoption as a result of water availability, while in Moore and Dinar (1992) they represent the water-allocation change as a result of water availability. In addition, Moore and Dinar (1992) argue that under conditions in California, water is a quantity-rationed input as opposed to a price-rationed input. Therefore, policies aimed at controlling water saving via price instruments are less effective than policies relying on quotas. Dinar et al. (1992) estimated the surface-water elasticity with regard to surface-water price at 0.49 and very significant. Again, one should remember that these studies measured two different things: water allocation and irrigation technology shares.

Table 2--Elasticity ranges for key explanatory variables, at either the farm or field level

Variable	Farm level	Field level
Principal component variable for environmental conditions	-0.146 – -0.081	
Field share with salinity and drainage problems		0.063 - 0.064
Surface-water cost	0.485 – 0.492	
Groundwater cost	0.666 – 0.683	
Surface-water quota	-0.036 – -0.027	
Average water cost		0.098 - 0.111

Source: Dinar et al. (1993).

One can distinguish two stages in the production decision process. If water is the limiting input, as is the case in the WSJV, then increased surface-water prices may induce adoption of water-saving technologies. The water saved can be used on lands that have not been in use before. The bottom line is that water was not saved, but it has been used more efficiently.

It can be concluded therefore, that adoption of modern technologies does not necessarily save water. The overall result, which is dependent upon local conditions, implies that policies to save water per se or to reduce water-quality-related problems should be considered and tailored to the region under consideration and not be adopted across the board.[9] Moreover, there is a need to recognize the necessity for synchronization between policy goals and policy instruments.

Drainage-Water Treatment, Reuse, and Disposal

Rhoades and Dinar (1991) introduce the concept of agricultural drainage-water reuse and its economic merits. Using a static model, they demonstrate that agricultural drainage water of relatively low quality is associated with benefits that can be recognized better if this water is separated from the fresh water and applied to salt-tolerant crops. An additional environmental benefit has been demonstrated through a significant reduction in drainage water disposal in the neighboring river. In a stylized example, the Rhoades and Dinar model suggests changes to regional income from agricultural production that is dependent upon reuse strategies (such as mixing ratios, or time during stage of growth of drainage reuse) and such exogenous variables as crop-yield price and surface-water price.

Swain (1991) demonstrates the implementation of the reuse concept in the planning process conducted by the SJVDP. In this case, the reuse stations not only allow for conventional crops, but also eucalyptus trees, halophytes, and, finally, small-scale evaporation ponds. While Swain evaluates the reuse sequence in a stylized setting, much effort is being invested in California to find the appropriate combinations of types of salt-tolerant eucalyptus trees (Cervinka, 1990).

Stroh (1991) introduces the concept of land retirement and analyzes a series of management alternatives—such as treatment, dilution, pumping, evaporation—evaluated against land retirement to minimize social cost, i.e., the drainage damage cost in the case of policy action. The term *land retirement* refers to the policy of removing land from commercially irrigated agricultural production. A policy to retire land in an area subject to high groundwater tables contaminated with elevated levels of selenium implicitly assumes that the net social benefit produced on these lands over time is lower than the cost to society of purchasing these lands. In order to calculate empirically the different cost items associated with this policy, different technological solutions have been incorporated, and their costs and selenium-reduction efficiencies were estimated. Some of the technologies are in a relatively early stage of development and the technical as well as economic parameters are not yet well established. Based on the available information, Stroh concludes that when comparing the cost of land

[9]For a comprehensive review of the literature on adoption of irrigation technologies, see Caswell (1991).

Table 3 -- Net social cost per acre of land retired

Increase in water value (Dollars/af)	Annual return to land forgone (Dollars/acre)			
	75	125	150	250
0	75	125	150	250
125	-50	0	25	125
150	-75	-25	0	100
250	-175	-125	-100	0
300	-225	-175	-150	-50

Source: Stroh (1991).

retirement with the costs of alternatives that physically manage drainage water, the value of the drainage coefficient is critical. Also, the alternative current use of the land and the future use of the water released are key factors in the economics of land retirement. In table 3, the net social cost associated with land retirement is presented for different values of water in other uses calculated for alternative returns to land forgone.

Water Markets

A study investigating the effects on water conservation, economic efficiency, and drainage and environmental pollution of a hypothetical water market was applied to the WSJV (Dinar and Letey, 1991). Results suggest that under a variety of conditions, a water market enables the farmer to both invest in improved irrigation technology and to pay for the safe disposal of drainage produced on his fields. Other societal benefits include a reduction in environmental pollution and benefits to the urban sector from additional water available for urban consumption.

Dinar and Letey (1991) also included in their analysis of water market opportunities the externalities via drainage disposal costs. Values in table 4 demonstrate water market and incentive system effects on individual irrigator decisions and private and social returns to 1 acre of cotton. The condition analyzed in the table is for a water quota equal to 3 acre-feet per acre and the environmental costs associated with drainage water are $36 per acre. When the drainage costs are not internalized, the farmer reacts as if there were no drainage costs. The drainage volumes are multiplied by the environmental costs to determine the social costs associated with environmental degradation. The net social benefit is the difference between the returns to the farmer and the social costs associated with drainage water pollution. When the drainage costs are internalized (the irrigator bears that cost), the social benefits are identical to the returns to the farmer. The social benefits are always higher when drainage costs are internalized than when they are not internalized. However, notice that the difference

in social benefits for the internalized and non-internalized cases becomes smaller with the presence of a water market and decreases successively with increasing water-market prices.

The urban sector benefits because the water market induces increasing water availability for urban uses. Assuming that the water-market price reflects the urban sector's willingness to pay, then the consumer (urban sector) economic surplus (social benefit) is higher with a water market than without one. This is particularly true and significant with increasing urban growth and water demands on the one hand, and limited and very expensive options for developing new fresh-water supplies on the other. The environment is enhanced by water marketing from two points of view. First, the water market induces a shift in irrigation technology and water management leading to lower volumes of deep percolation. Deep percolation provides the transporting medium for agrochemicals that serve as pollutants. For example, nitrates, pesticides, or inherent toxic soil elements can be transported by deep percolation to ground water or drainage waters that reach the surface. Reduction in deep percolation reduces the transport of potential water contaminants. Second, with a water market, the farmer can afford to pay relatively high costs for disposal of drainage waters and still maintain his profit margin vis-a-vis the nonmarket case. The social costs associated with nonpoint source water pollution that are not internalized by the farmer are also reduced in the presence of a water market.

In a study by Weinberg and Willey (1991), the physical model used by Dinar and Letey (1991) was applied on a regional scale to two subareas on the WSJV. The study considered, among other alternatives, a scenario of water marketing. The regional results are similar in nature to the results obtained in the Dinar and Letey micro-level analysis. Prices for water in the market varied from $10 to $140 per acre-foot. Entry into water markets also varied among the modeled regions. A water market price of $125 generates water sales, varying from 0.5 to 1.5 acre-feet per acre. In addition, drainage reductions range from 0.65 to 1.24 acre-feet per acre. In summary, with higher water-market prices, water sales increase, applied irrigation

Table 4--Private returns, social cost, and net benefits for different water-market prices when environmental costs are internalized and not internalized

Actual market price	Drainage costs not internalized: Profit	Drainage	Social cost	Social net benefits	Drainage costs internalized: Social net benefits
$/af	$/acre	af	$/acre	$/acre	$/acre
0	463	1.94	115	348	421
37	463	1.94	115	348	428
62	463	1.45	86	377	444
99	480	0.24	14	466	471
148	497	0.16	10	487	490

Source: Dinar and Letey (1991).

water decreases, management and technology levels increase, drainage flows from the region decrease, and regional income increases. However, significant differences among modeled subareas are the result of specific circumstances of cropping patterns, water endowments, and physical conditions within each subarea.

It should be noted that Howitt et al. (1992) evaluate the performance of the "drought" water market established in California in 1991. The water market was established in California to create a safe source of water for regions that face a limited supply of surface water, and where water allotments were cut by substantial amounts due to drought conditions. As will be discussed later, in its first year of operation the market price for water was set by the California Department of Water Resources at $125 per acre-foot, which created a surplus of water in the drought waterbank. In the following year, which was also a drought year, price was reduced to $50 per acre-foot, and the quantities sold were significantly lower than in the previous year. This fact becomes an important consideration when reviewing the results of the study by Weinberg and Willey (1991), although one should also consider the regions that were involved in the sale of water in California's drought water market. Water sales originated in northern California, while water purchases originated in the SJV and other urban areas in 1991.

Public Health and Fish and Wildlife Measures

Numerous studies have investigated water-quality problems in the context of human risk and of fish and wildlife and other environmental amenities. Research approaches have been contingent on whether or not the amenities (goods) have a market value.[10] In this section we will summarize a few studies that are relevant to the water-quality problem in the WSJV and that provide implications for drainage-water management aspects.

Three studies are probably the state of the art with regard to the implication on humans of selenium in drainage water (Klasing, 1991), on fish (Saiki et al., 1991), and on avian wildlife (Skorupa and Ohlendorf, 1991). Although not all provide implicit analysis of policy measures and their consequences, it is clear that several policy-related statements can be used. From Skorupa and Ohlendorf, it is clear that at the current state of knowledge: (1) many factors can influence relationships between the level of selenium in water or soil and environmental risk, (2) local site conditions vary dramatically and should be taken into consideration, and (3) the social goal should not be selenium occurence prevention (which might not be achieved given all the opposing interests and powers), but rather minimizing selenium levels.

Klasing (1991) argues that most alternatives for solving drainage-related problems are not without potential public-health impacts. Evaporation ponds for storing and evaporating drainage water may present significant human hazards through bioaccumulation in the food chain. Bioaccumulation may occur as a result of humans consuming avian wildlife contaminated by drainage water in the ponds. Public health impacts may also occur because

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[10]For the most recent major studies in the field of measuring benefits from non-marketed environmental amenities, see Smith and Desvousges (1986), Braden and Kolstad (1991), and Mitchell and Carson (1989).

Table 5--Willingness to pay for different environmental programs in the San Joaquin Valley

Program	Out of State	San Joaquin Valley	Other California regions
	Dollars per household per year		
Maintain wetlands	92	174	--
Wetlands improvements	161	286	252
Avoid contamination of wildlife at evaporation ponds beyond current levels	93	197	--
Reduce contamination at evaporation ponds	131	360	308
Improve San Joaquin River salmon fishery	103	202	181
Combined programs	198–452	355–1448	283–438

Source: Jones and Stokes Associates (1990).

drainage-water treatment processes may generate entirely new contaminants (such as bacterial sludge) and human exposure scenarios.

Saiki et al. (1991) introduced selenium mobility via river water and fish to the food chain of humans. Although not explicitly discussed in Saiki et al., an important policy implication of water quality degradation and mobilization of selenium-tainted water is the randomly open access to water by individuals who may be negatively affected by the contaminants accumulated in the water and fish. This problem has not yet been addressed in regulations covering water quality and public health.

Still another issue is the economic quantification of environmental amenities. The management alternatives suggested in SJVDP (1990) were investigated in Jones and Stokes Associates (1990) to establish relationships between resource conditions and public values at several resource levels. Without discussing the complexities associated with the above research, dollar value results are presented in table 5.

The results of this study were considered "consistent indicators of value, and accurate measures of actual dollar amounts that people would spend in the circumstances described in the survey" (Jones and Stokes Associates, 1990).[11] Total willingness to pay for the individual programs (based on the number of households in the surveyed regions) ranges from

[11]This does imply that the above reported values are accepted without criticism. The reader is referred to Burness et al. (1991) for a general criticism on the research method used for evaluation of values of nonmarketed goods.

$1.76 billion to $3.34 billion. These numbers may have significant implications for policy purposes, assuming that interest groups with similar perceptions will be involved in future actions to manage the WSJV water-quality problem.

Regional Approaches

Several studies have dealt with the regional aspects of drainage and salinity problems in the WSJV, using different approaches. The common feature of these studies is the modeling of both the physical characteristics as well as the economics of the problem. Most of the studies use static approaches. Static approaches ignore the dynamic nature of some state variables. Other approaches are based on empirically derived relationships; that is, local observations that may infer the relationships between state and decision variables used in the analysis. Other approaches are based on normative relationships in developing the physical aspects of the drainage problem.

Weinberg, Kling, and Wilen (1993) analyzed policy options for the control of agricultural drainage pollution using a steady-state model.[12] Options for reducing regional drainage volumes by 10, 20, and 30 percent were compared for different institutional settings that include taxes on drainage and on irrigation water standards for irrigation efficiency levels, subsidies for irrigation efficiency, and a water market.

The results in table 6 indicate very clearly that different policy instruments are associated with different net returns to agricultural producers. These policies are often evaluated by comparing producers' economic losses or gains associated with each policy. This approach omits possible effects on third parties and their costs. Third-party effects (externalities) associated with irrigated agriculture are the negative effects (costs) of agricultural drainage water. Including these social costs in policy analysis, may result in a considerable change in producer preferences compared with an analysis with only private considerations. For example, some of the policies in table 6 are associated with a relatively low volume of collected drainage (assumed to be positively correlated with social cost), but with a low dollar value for net returns per acre for agricultural lands. If social costs associated with drainage are not considered, these policies are probably less attractive than policies producing higher net returns and higher rates of drainage.

In a study of farmers' response to a voluntary program for drainage reduction, Wichelns (1991a) applied block-rate water pricing to a case study in a specific water district in the WSJV. The study was aimed at conserving water and reducing drainage. More detailed data is also provided in Wichelns (1991a) and Zilberman et al. (1992a) that support the hypothesis that agricultural producers are sensitive to price signals. The program has been implemented using a two-stage price scheme. Water price in the first block was set to the previous historical single price of $16 per acre-foot, and then for each crop a tier level (see table 7) was established at a higher price rate (Wichelns, 1991a). The price of water in the second

[12]A steady-state solution assumes that if an optimal solution is found, it can be kept at that level for the entire planning period.

Table 6--Responses to policies for 10-, 20-, and 30-percent reductions in regional drainage volume

Policy instrument	Fallow acres	Collected drainage	Water sales	Net returns
	Percent	af/drained acre	af/acre	$/acre
Base case	5	0.69	na	339.40
10-percent reduction				
Drainage tax ($100/af)	3	0.62	na	297.30
Water market ($72.5/af)	8	0.62	0.31	359.02
20-percent reduction				
Drainage tax ($132/af)	3	0.55	na	284.88
Water market ($88/af)	15	0.55	0.65	365.73
Uniform water tax ($87.5/af)	16	0.55	na	93.81
30-percent reduction				
Drainage tax ($191/af)	3	0.48	na	265.37
Irrigation efficiency:				
Standard (IE 83%)	2	0.48	na	317.59
Uniform water tax & irrigation efficiency subsidy ($75/af & 25%)	8	0.48	na	145.28

na = not applicable
Source: Weinberg et al. (1993).

Table 7--Crop-specific average irrigation depths (applied water) for major crops, associated block-rate tier levels[1], and surface-water supply and drainage

Crop	Crop-specific average irrigation depths for major crops						
	1986	1987	1988	1989	1990	1991	Block-rate tier level
				Feet			
Cotton	3.21	3.31	3.27	3.34	2.84	2.40	2.9
Tomatoes	3.21	3.29	3.15	2.72	3.03	2.69	2.9
Melons	2.15	1.99	2.20	1.93	1.79	1.46	1.9
Wheat	2.01	2.55	2.35	3.02	2.18	1.60	2.1
Sugarbeets	5.01	3.81	4.92	3.73	2.54	*	3.9
Alfalfa seed	2.13	2.24	1.80	1.84	1.88	1.36	1.9
Rice	5.72	5.24	5.99	5.40	*	*	5.1
Regional surface-water supply and collected drainage:				Acre-feet			
Water deliveries	26,000	24,000	26,000	27,000	17,000	6,500**	
Drainage water collected[2]	4,896	4,197	3,307	3,058	2,706	***	

* Not grown.
** Not final.
*** Data not available.
[1]Price scheme in which rate change for block quantities, i.e., price p_1 for quantity between 0-q_1, price p_2 for quantity between q_2-q_3, etc.
[2]Total area drained is 4,900 acres.
Sources: Wichelns (1991a, 1991b), Zilberman et al. (1992a).

block was set to $40 per acre-foot. It should be mentioned that producers are also subject to an annual fee of $42 per acre to cover the fixed costs of district operations.

Information in table 7 sends a mixed signal. First, it is clear that the drought effect is significant. Reduced surface water of about 25-65 percent of normal supply will motivate farmers to conserve and be more efficient. Second, there is the trend of reduced water applications from the first 4 years of data. Therefore, table 7 indicates a sharp decline in applied water, and the consequent drainage volumes are obvious.

Hatchett, Horner, and Howitt (1991) present the framework and an application of a mathematical programming model that links agricultural production to groundwater hydrology and drainage. The model was applied to two subareas and was used to evaluate surface-water pricing policies on subsurface drainage generation. The results are similar to those in the studies reported earlier; therefore, only the policy-oriented conclusions of this study are discussed here. The direct connection between high water tables and groundwater in the unconfined aquifer leads to the conclusion that any policy that results in less groundwater pumping is likely to aggravate the drainage problem. Since the surface-water allocation to individual agricultural producers does not meet their water quotas, at least in the drainage-problem areas, the shadow price (opportunity cost) of water is higher than the contract price. If groundwater is accessible, then the pumping costs should serve as an estimate of that shadow price for water, and should be used as an indicator of the opportunity value (cost) of contract water. Pumping costs that are less than the shadow price of water encourage groundwater use.

Horner, Hatchett, House, and Howitt (1991) expand on the work in previous studies to include the effects of different policies on the local, regional, and national economies. A mathematical programming model that includes physical components similar to those in Hatchett et al. (1991) is developed and connected to the California Agricultural Resource Model (CARM), which is then connected to the U.S. Mathematical Programming Model (USMP). Water-quality-related policies are evaluated in conjunction with water and drainage problems in the WSJV. Several scenarios are analyzed. A "base" scenario includes the current economic, physical, and institutional conditions and assumes that they will remain unchanged for the entire time horizon of the analysis (10 years). A "worst case" scenario was then devised and evaluated relative to the base scenario. The worst case scenario includes severe environmental regulations, affecting only the WSJV, that prohibit off-farm drainage disposal and limit reuse of agricultural drainage for irrigation purposes only. Responses of WSJV producers to these regulations can take the form of installing tile drains, increasing reuse of drainage water, and changing cropping patterns. The two scenarios were analyzed (1) using current cotton prices, and (2) assuming a 20-percent reduction in cotton prices to take into account proposed changes in government commodity programs.

Results, using current cotton prices, indicate a moderate decline in irrigated acreage (0-4 percent) and in farm income (5 percent) for the first 5 years and then, for the next 5 years, a large drop in farm income (9-17 percent) and in irrigated acreage (0-9 percent). These changes are not considered drastic, and Horner et al. state that "irrigators will be able to survive financially in the near term...." A 20-percent reduction in cotton prices, combined

with the above-mentioned environmental regulations, would cause devastating effects to the well-being of agricultural producers. Cotton acreage would be expected to be reduced in different production regions by 9-84 percent (depending on available cropping alternatives). Farm income would be expected to decline (compared to the base run) by 19-49 percent, and irrigated acreage to decline by 16-22 percent.

One important conclusion from Horner et al. is that spatial and physical characteristics should be taken into account when national policies are formulated. Changes in commodity policies can change regional cropping patterns, resource use, and environmental quality.

A study by Moore, Negri, and Miranowski (1991) analyzed the role of Federal commodity and water-reclamation programs in California. A behavioral model was estimated econometrically using data from the U.S. Bureau of Reclamation. The model was used to simulate water and crop-acreage policies aimed at conserving scarce irrigation water. Although the analysis does not include water-quality aspects, it provides regional responses that are comparable to those analyzed by Horner et al. (1991). They also provide estimates of the reduction in California crop supplies as a result of the reduction in water supply, or a crop set-aside ratio (according to the Federal crop program). The results suggest that the response to a 10-percent reduction in surface-water supply would affect different crops in different ways. Rice, cotton, vegetables, and wheat are affected the most (reductions in harvested acres of 4.4, 2.5, 2.3, and 1.6 percent, respectively), as opposed to fruits and nuts, which increase in acreage. The water savings under the wheat set-aside ratio are similar in magnitude with respect to the crops analyzed, but less effective than the water-supply-reduction policy. This fact means that, under the conditions analyzed, the crop set-aside policy is less effective in water savings than is the direct cut in surface-water supply.

Dinar et al. (1991a) developed a regional optimization model aimed at evaluating policies to control the quantity and quality of drainage water from agricultural lands. The physical model consists of a steady-state crop-water-production function that describes the relationships among water quantity and quality and crop yield, and quantity and quality of the irrigation drainage water.

The regional model was used to determine optimal results for alternative policies and combinations of policies. Empirical relationships (summary functions) between regional income and policy instruments (tax or constraint levels), between drainage quantity and policy instruments, and between drainage quality and policy instrument levels were estimated using optimal solution results generated by the regional model.[13]

To use such relationships so that a regulatory agency could determine optimal values for policy instruments (separately or in combination), relative values must be placed on policy goals such as regional income and pollution load. It has been shown that for each policy

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[13]This method of producing summary functions from optimization models has been called "pseudo data." See Griffin (1987) for basic reference, Braden et al. (1987) for an application to environmental policy. The nature of the functions in the physical model determines the nature of these relationships (see Dinar and Letey, 1991).

instrument, the marginal effect on regional income in the optimal solution equals the sum of the marginal social costs associated with quantity and quality of the drainage water. Marginal social costs here assume a range of values, since the social costs are not known at present. Therefore, optimal policy levels will depend on the external value assumed.

Table 8 demonstrates the use of the summary functions for finding optimal values for policy instruments (in this case, considering each policy instrument separately) for varying values of the social cost associated with disposal of regional irrigation drainage. With a zero social cost associated with drainage disposal, the optimal policy-instrument value equals the level associated with the case of no regulation. As the social cost of drainage disposal increases, the optimal tax level on drainage water increases. Similarly, the optimal constraint level on drainage volume disposal decreases. In two cases (a tax on surface water and constraint on surface water), the optimal values for the policy instruments remain at the no-regulation level for the assumed social cost values.

Table 8 also presents regional net income effects of policy instruments relative to the income in the unregulated case. Of the three policy instruments most effective at reducing salt load, the tax imposed on drainage causes the most rapid decline in regional income as social cost increases, and the drainage constraint causes the least reduction in regional income as social cost increases. For a social cost of $5 per ton of pollution load, the optimal drainage constraint of 63,000 hectare centimeter (95 percent of the base case) reduces regional net income by only 5 percent, whereas the optimal drainage tax for the same social cost reduces income by 33 percent. The tax and the constraint on surface-water use reduce income by roughly similar amounts (14 and 19 percent, respectively). Even with a social cost of $20 per hectare centimeter (ha cm), the optimal drainage constraint reduces income by 12 percent at most.

Several conclusions from this study apply. First, to achieve the social goals of reduction of pollution load at the lowest cost in regional income, a combination of policy instruments may

Table 8--Optimal values for policy instruments for various social drainage-disposal costs (p^L)

	Optimal policy instrument value					Regional net income				
	Tax		Constraint			Tax		Constraint		
p^L	Drainage	Surface water	Surface water	Drainage	Load	Drainage	Surface water	Surface water	Drainage	Load
$/ha cm[1]	--$/ha cm--		--ha cm--		ton	Percent of unregulated				
0	0	2.5	400	66	40	100[2]	100	100	100	100
5	25	2.5	400	63	20	67	86	81	95	80
10	29	2.5	400	43	15	63	72	62	92	67
20	34	2.5	400	30	15	60	45	24	88	43

[1]1 acre-foot = 12.35 ha cm.
[2]Corresponding to the regional net income in the case of no regulation ($1.15 million).
Source: Dinar et al. (1991b).

be more successful than a single instrument. Second, the heterogeneity of the physical characteristics of the parties in a region affects the contribution of each to the regional pollution, so differential policies may be needed. An agency, while designing policies to reduce pollution, should also consider the fairness and flexibility of allowing adjustment of the production system over time to prevent excessive removal of land from production.

Dynamic aspects of drainage and salinity accumulation in a farm or a regional setting were included in a study by Dinar et al. (1991b). Here, the physical model was based on empirically estimated production functions from a previously conducted experiment simulating conditions in the region. The model was used to evaluate alternative drainage-abatement-policy scenarios, including drainage quotas and taxes, surface-water supply quotas and taxes, and irrigation-technology subsidies. Policy-scenario results differ in the time to achieve steady-state values, and in the level of that value. Table 9 presents steady-state results for selected variables by policy scenario for this study.

Tax and quota policies are evaluated under the baseline gravity irrigation system. Cost-sharing is evaluated assuming conversion from the base gravity system to an improved, more water efficient sprinkler system. Under the cost-share scenario, amortized fixed system costs are reduced by a 60-percent cost-share subsidy (with no annual payment limit per farm operator). A 60-percent reduction in sprinkler costs (from $70-$27.4 per acre) yields a present value of farm returns ($162,500) that is roughly equivalent to baseline returns. At this level of subsidy, a farmer is indifferent to system conversion, while society gains from water conservation and pollution-reduction benefits that may justify a public subsidy for improved irrigation technologies.

Table 9 shows present value of farm returns for selected scenario levels by policy instrument. Total farm income over the planning horizon declines under all policies evaluated, with the exception of the cost-share scenario. In general, income reductions are small for marginal changes in taxes and quotas, as farmers adjust inputs to minimize income reductions. As tax and quota levels become more restrictive however, income reductions are increasingly significant. Income reductions are generally greater for water use policies than for drainage policies, under a given percentage increase in tax or quota level.

Notable among return estimates are negative social returns associated with the technology cost-share policy. This result suggests that technology subsidies alone do not represent an attractive public investment under base empirical assumptions. Low-valued field crops and adequate supplies of relatively low-cost irrigation water limit the potential for enhanced returns under water-conserving technologies. Findings of a similar nature have been cited in other technology adoption studies (e.g., Caswell and Zilberman, 1986; Caswell et al., 1990; Dinar and Zilberman, 1991). However, the model does not account quantitatively for unmarketed benefits associated with drainage reduction and water conservation. A technology cost-share can be socially justified in cases where these benefits exceed the technology subsidy.

Total water use varied substantially under alternative policy instruments. Aggregate water use was most significantly affected by direct quotas and taxes on surface water. It is notable that significant drainage restrictions resulted in relatively small reductions in water use. Per acre

Table 9--Steady-state levels of selected variables, by policy scenario

Item	Total present value: Private farm income	Public revenue or cost	Total social income[1]	Steady state achieved	Value at steady state: Annual income	Total land use	Total water use	Surface water use	Ground water use	Drainage water	Soil salinity
	---------$1,000---------			Year	$1,000	Acres	-------------Acre-feet-------------				EC
Baseline	162.5	0	162.5	4	13.2	500	2118	1326	792	439	3.00
Surface-water tax[2]:											
$5/af	93.0	67.1	160.1	4	6.8	500	2021	1234	787	357	3.01
$10/af	34.7	110.6	145.3	6	1.5	412	1648	1000	648	278	3.01
Drainage tax:											
$10/af	125.4	30.1	155.5	4	9.6	500	1965	1183	782	288	3.02
$20/af	100.3	41.1	141.4	4	7.2	500	1868	1096	772	194	3.04
$30/af	83.3	41.7	125.0	5	5.6	500	1798	1035	763	129	3.05
$50/af	57.8	62.7	120.5	6	3.3	500	1743	1000	743	115	3.05
$70/af	32.8	86.9	119.7	5	1	489	1743	1000	743	115	3.05
Surface-water quota (af/yr):											
1250	161.1	0	161.1	4	13.0	500	2038	1250	788	371	3.01
1000	145.5	0	145.5	6	11.5	412	1648	1000	648	278	3.01
750	113.7	0	113.7	8	8.6	310	1236	750	486	208	3.01
500	81.1	0	81.1	13	5.8	207	825	500	325	137	3.01
Drainage quota (af/yr):											
350	160.4	0	160.4	4	12.9	500	2027	1241	786	350	3.01
300	156.9	0	156.9	4	12.6	500	1976	1193	783	300	3.02
250	151.3	0	151.3	4	12.0	500	1925	1147	778	250	3.03
200	143.1	0	143.1	4	11.2	500	1874	1102	772	200	3.03
100	109.5	0	109.5	6	7.8	500	1753	993	760	100	3.11
Irrig. technology cost share:											
40%	162.5	-237.0	-74.5	3	13.4	500	2098	1298	800	411	2.64

[1] Social income estimates do not include off-site benefits.

[2] Water tax added to both base and supplemental surface-water supplies.

application rates declined at a lesser rate, as reductions in water use were offset to some extent by reduced acreage irrigated.

In general, direct policies targeting drainage will achieve drainage goals more cost effectively (in terms of reductions in social returns) than indirect policies targeting water use that contributes to drainage. From a practical standpoint, however, drainage-based policies may be difficult to implement since hydrologic monitoring is both imprecise and relatively expensive (although those costs are not reflected here). That surface water quota policies achieved the drainage target with only small declines in social returns relative to direct drainage policies is encouraging from a policy perspective. Surface water quota and tax policies were equally cost effective in achieving the drainage goals.

The technology-cost-share scenario involving a shift from gravity to sprinkler systems failed to achieve the drainage reduction goal of 37 percent. While soil salinity and drainage per unit of land were reduced relative to the baseline, aggregate drainage remained high relative to other policy scenarios. This is due to comparatively high water-application rates and preservation of an irrigated cropland base. Findings suggest that technology-cost-sharing must be combined with other more effective quota and tax policy instruments to be effective as a drainage management strategy.

Conclusions from the dynamic model suggest that policies should be evaluated while trade-offs are kept in mind. For example, drainage-reduction policies may contribute to increased soil salinity, with implications for long-term productivity of soils. Water-tax and quota policies may result in reduced irrigated acreage and farm income, with impacts on local economies. On the other hand, technology subsidies may result in maintenance of irrigated cropland base, with implications for aggregate water use and drainage generation.

The empirical analysis generally supports the findings of earlier dynamic-modeling studies on irrigation drainage and salinity (e.g., Knapp, 1991). The most significant response to policy adjustments in this analysis involves reduced irrigation applications per unit of land, with adjustments in surface- and groundwater shares. Land allocations are relatively stable, both over time and across policy scenarios. The steady-state solution is reached, in most applications, relatively early in the planning period.

A third related study (Dinar et al., 1993) attempts to compare the results of the steady-state and the dynamic models, and to extend the scope of the policy analysis to include institutional arrangements for regional cooperation.

Several policies and scenarios were compared, including surface-water quota and surface-water tax policies. The base policy scenario was represented by a full water quota and unrestricted drainage quantity. Relative effects on the present value of regional income and steady-state drainage volumes for the policy instruments analyzed are plotted in figures 5 and 6. In the case of a water quota, a reduction in surface-water entitlements of 17 to 40 percent of base scenario supply resulted in a decrease in regional income of 1 to 50 percent. A similar but stronger effect was observed assuming a policy involving water tax, where an increase of 50-100 percent in the cost of surface water resulted in a 43- to 79-percent

Figure 5
Relative Effects on Regional Income and Drainage Volume of Changes in Water Quota in the Steady-State Model

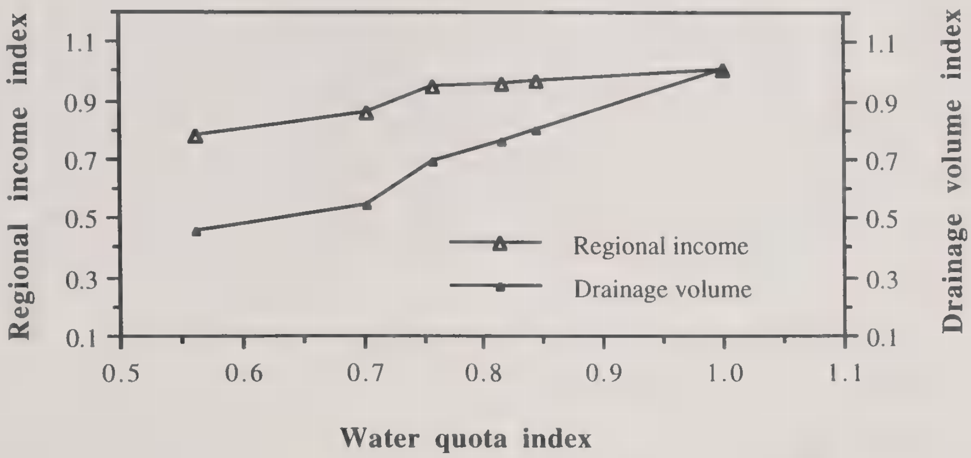


Figure 6
Relative Effects on Regional Income and Drainage Volume of Changes in Water Tax in the Steady-State Model

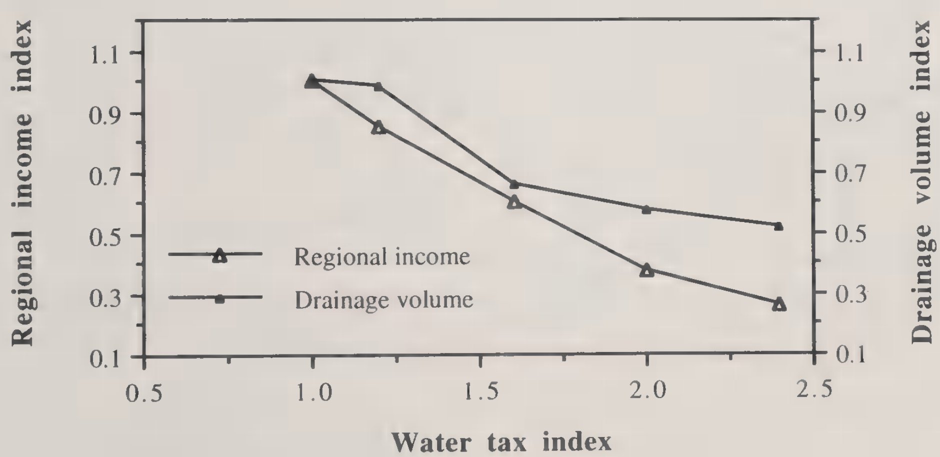


Figure 7
Relative Effects on Regional Income and Steady-State Drainage Volume of Changes in Water Quota in the Dynamic Model

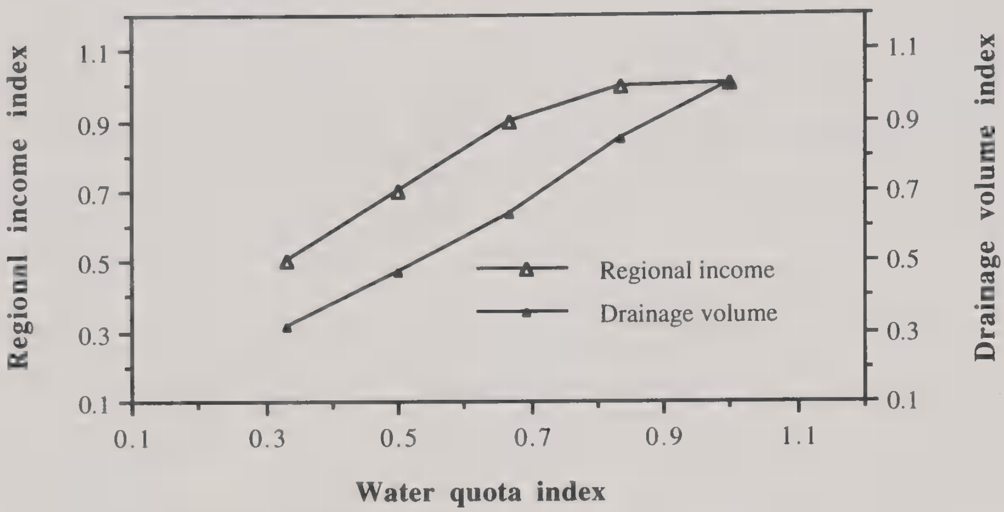
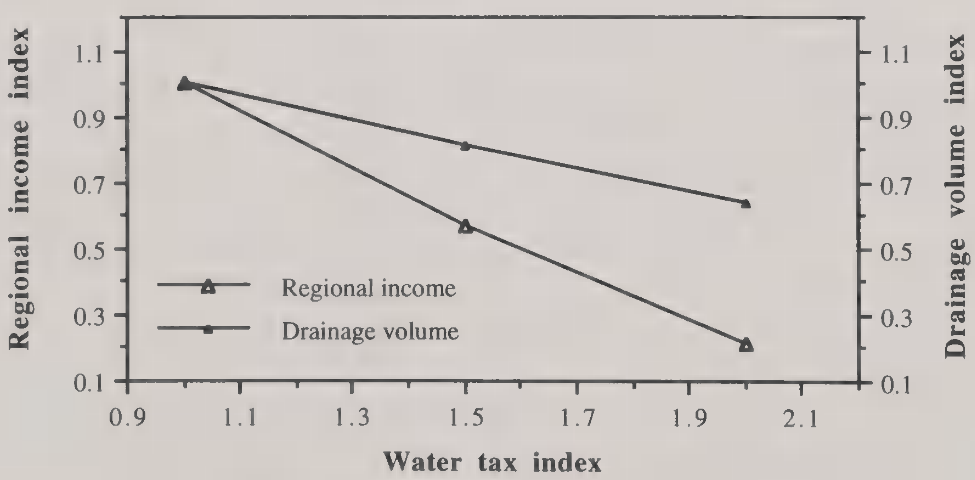


Figure 8
Relative Effects on Regional Income and Steady-State Drainage Volume of Changes in Water Tax in the Dynamic Model



decrease in regional income. Even if tax revenues are reflected in regional income, income levels under water taxes are lower than under water quotas over the range of the values of the policy variables evaluated. Similar trends in regional income and drainage flow were observed for the case of the dynamic model (figures 7 and 8).

Comparison of the two models indicates that under both steady-state and dynamic situations, results for regional income and drainage flow were very close. The effectiveness of the two policy tools to reduce irrigation-drainage pollution can also be evaluated. While both policy instruments achieve a reduction of almost 50 percent in drainage volume over the range of values analyzed, the water-tax policy is associated with a lower level of regional income. If taxes are considered in regional income calculations, the decrease in regional income is still relatively larger in the case of water taxes than for water quotas.

Water Rights and Water Quality

Policy analysis of water quality in California has to recognize that water is not presently allocated by market or market-like mechanisms, but rather by institutionalized water-rights regimes. Most water-rights regimes are, in essence, queuing rules. The most important water-rights rule in California is prior appropriation rights. The allocation system is characterized by two principles: (1) first in use is first in right, and (2) use it or lose it.[14] These two principles characterizing the water allocation mechanism in California contribute to water quality problems on the WSJV and also cause difficulties in achieving improved water allocation efficiency in other parts of the State.

The prior-appropriation water-rights doctrine is similar to the homesteading approach to land allocation. The process of homesteading in the 19th century was aimed at encouraging people to settle in the West, and was based on the principle of "first in use is first in right." Namely, once you work the land and settle on it, it is yours. Recent studies show that this approach to settlement was quite effective and was preferred over putting land up for bidding by government officials. The main reasons for the homesteading approach's superiority in land settlement was because the land had been abandoned by the settlers, and the U.S. government wanted to accelerate the settlement process, ensure as much investment in land as possible, and increase production. Obviously, as time went on and new land reserves were exhausted, there was a transition from homesteading toward formal land markets.

The analogy to water is appropriate. Much of the water under appropriation rights was initially viewed as a free product of nature. Additionally, the government wanted to encourage people to invest in diverting this water and settle on the lands it irrigated. Especially in the 19th century, when parts of California's Central Valley were settled, government resources for building infrastructures in the West were minimal. The State

[14]This approach is explained very well in the articles by Cuzon and others (particularly the article by Gardner), in *Water Rights: Scarce Resource Application, Bureaucracy, and the Environment*, edited by Terry L. Anderson (1983). A more formal analysis of this approach and its implications are in Burness and Quirk (1979).

government wanted to encourage the private sector and, by using queuing rules, it established some order and removed uncertainty about water rights, thus enabling people to invest in diversion activities.

During the 20th century, when surface water was being developed for agricultural use in the West, water supply far exceeded demand. For economic and political reasons, the U.S. Bureau of Reclamation used the prior appropriation doctrine as the framework for allocating water supplies through water contracts. This approach enabled the quick utilization of water, the extension of the agricultural land base to the west side of the Central Valley, and increased land use on the east side of the San Joaquin Valley.

Shah et al. (1993) argue that prior appropriation rights may be efficient when there is an abundance of water and its scarcity value is limited, because it allows the use of water with a rather low investment in infrastructure, such as conveyance systems and canals. When water becomes scarce and a water market is established, there is a need for investment in water conveyance and monitoring equipment to protect against illegal diversions of water. This may involve expensive piping facilities to extend canal capacity. Under prior appropriation systems, when water is not of high value to senior rights owners, water canals can be open and pass through the land of senior rights owners without any risk of illegal diversion. This leads to low investment in diversion capacity and allows farmers to invest in other activities.

Transition to water markets may make water transactions much more complex. Such institutional arrangements may require much more flexibility than the queuing system, which usually requires longer canal systems, because generally seniority is associated with proximity to the water source. Thus, transition toward developed water markets may require a substantial investment in infrastructure. However, as Shah et al. have shown, when water is perceived to be readily available and the gain is not that large from a water-market-based allocation system, then it may be that the cost of monitoring and updating the allocation system to prevent illegal diversions may be larger than the gain associated with it. Therefore, it may be that a prior appropriation system is superior to a market-like allocation of water, when water is abundant. Alternatively, when the gains from a water-market allocation system are greater than monitoring and installation costs, institutionalizing such arrangements would encourage efficiency and reallocation of existing water supplies.

With prior appropriation systems, farmers with rights to relatively large volumes of water are not provided much incentive to conserve water or to invest in modern irrigation technologies that would reduce water use, increase efficiency, and generate extra water that could be used to expand the land base or be utilized outside of agriculture. Furthermore, with the unlined canals that generally accompany prior appropriation systems, there is much loss of water during conveyance. Transition to market-like mechanisms for water allocation may increase water-use efficiency. Farmers who are senior-rights owners will have additional incentive to adopt modern irrigation technologies, reduce their water use, and sell the extra water given that the price is right and they own the rights to the water. When water rights are not transferable, the incentive for senior-rights owners to conserve water and sell it on the market is rather limited. Shah et al. argue that under such circumstances, senior water-rights owners will object to any reform that would move from a queuing system to water markets.

Following the above discussion, it is clear that when there is a sufficient demand for water by junior-rights users in agriculture or in the nonagricultural sector, a transition from an appropriative water rights regime toward a market-like mechanism for allocating water may lead to water conservation and increased economic efficiency. Obviously, such a transition may involve investment in infrastructure that improves water-conveyance facilities. The costs of this transition should be taken into account in the water-reform decision process. However, while most water-reform policy analysis considers water quantity issues, the transition to water-market mechanisms also has a large impact on water quality. Use of traditional irrigation technologies, like furrow and flood irrigation, as well as the reliance on unlined canals for transfer of surface water under the prior appropriation system, generates a great deal of deep-percolating water, which has substantial implications for water use and particularly water quality.

On the east side of the San Joaquin Valley (SJV), this percolating water builds groundwater aquifers, which over time have had uses of their own. For example, most of the cities in the Central Valley—Fresno, Madera, etc.—have relied on groundwater for urban consumption. Generally, groundwater is cheaper. It is available throughout the year, and its treatment costs are lower because it requires less treatment (fluoridation). For these reasons it has been used extensively by eastern SJV cities.

Groundwater aquifers have also been used for irrigation on a continuous basis, particularly as part of a conjunctive-use scheme. As recent studies demonstrate (Zilberman et al., 1992b), the availability of groundwater aquifers allowed California's agricultural sector to survive the current drought. The traditional approach to irrigation in California—using surface irrigation to generate deep percolation, which generates groundwater that is used as a backup supply in case of droughts and as a source of water for cities and junior-rights owners—seems by many to be almost perfect.

However, this system has several flaws. First, agricultural production involves the use of chemicals, particularly nitrates, as well as salts. Over time, groundwater becomes more saline and contains increasing levels of nitrates, so that its quality for urban consumption and for use in agricultural activities declines. In some cases, groundwater quality declines because of the accumulation of pesticide residues. The accumulation of chemicals (e.g., DPCP) from agricultural use many years ago in the Fresno area was a major subject of concern. Thus, even in areas where the groundwater can be easily used, the use of traditional irrigation technology and the replenishment of the aquifer has caused water quality problems that are of concern now and may be of more concern in the future. Reliance on the prior appropriation system and the water-use practices that it induces has many more ramifications in areas with geologic formations that are prone to waterlogging problems. The drainage problem discussed above is an example of such phenomena. As described, the west side of the San Joaquin Valley has a layer of impenetrable clay that accumulates groundwater close to the surface and raises the groundwater level to an extent that endangers the existence of agricultural production. Growers in this area have relied on traditional irrigation technologies and generated relatively high levels of deep percolating water that started and accelerated the waterlogging process. In many cases, subsurface drains have been installed to alleviate this problem. However, disposal of water collected in these drains contributes to surface-water

quality problems. Obviously, a transition to water-market-like mechanisms that increase the value of water and provide farmers with incentives to adopt modern irrigation technologies will reduce deep percolation and significantly slow the waterlogging process.

There are several indicators of the importance of water-rights systems in generating drainage, and the potential of a transition to water markets can be studied from the California agricultural response to the recent drought. A study by Macdougall, Hanemann, and Zilberman (1992) has shown that existing water-quality standards for the San Joaquin Valley were met by water districts such as Broadview, Pacheco, and many others during the drought. This occurred because farmers in this region, who rely on the Bureau of Reclamation's water for irrigation and who received much less water during the drought, enacted intensive water-conservation practices, adopted modern irrigation technologies, and drastically reduced their drainage. Furthermore, some water districts introduced schemes such as tiered pricing to encourage water conservation. These schemes seemed to be effective in reducing farmers' water demand as well as drainage.

The response to the drought also revealed a substantial difference of behavior between regular Federal and State water-project contractors and exchange contractors who have senior water rights. Exchange contractors differ from regular and Federal/State water-project contractors by having a guaranteed amount of water from any available source. Exchange contractors tend to have much higher water use and are much less likely to adopt modern irrigation technologies than regular contractors, who are most vulnerable to water cuts associated with drought. Therefore, regular contractors adopt modern irrigation technologies, generate less drainage, and have the potential to contribute less to the waterlogging problem.

A transition to water markets can reduce the waterlogging problem through several means. One, farmers who adopt modern irrigation technologies, in general, conserve water. Two, improved water-conveyance facilities would likely reduce conveyance losses, which are considerable in many parts of the SJV. Third, the adoption of modern irrigation technologies may also have a substantial yield effect (Dinar and Zilberman, 1991). So, unless farming is supported with commodity programs, the irrigation acreage of some crops may decline. All in all, the movement toward water markets, particularly through a system of transferable rights, may provide a substantial contribution to the drainage problem. Further evidence of this is in the study by Shah et al. (1993), which used optimal control theory to study optimal drainage taxation under alternative institutional regimes. This study suggests that, when the price of water approaches $75 per acre-foot, which is the effective price as a result of the drought, the effective penalty for drainage is substantial, so that the drainage problem in many parts of the State will disappear.

However, a transition toward water markets may create many problems that must be addressed. First, a transition to water markets in California must be accompanied by a policy to control and optimally use ground water. It may be that, with water markets, farmers will overpump groundwater reservoirs, which will lead to a water crisis in the near future. Therefore, any policy to move toward market-like solutions for surface-water problems has to include some sort of groundwater-monitoring program. Second, moving away from dependence on existing appropriative water-rights allocations may reduce much of the existing

groundwater aquifers and will drastically curtail their capacity. Such effects will likely have third-party implications. For example, more conveyance facilities (e.g., storage facilities) would have to be constructed to allow cities to replace groundwater resources with surface-water resources. In the long run, such movement may be reasonable because of the declining quality of groundwater. In the short run, however, it may be costly. Part of the proceeds of water markets may be sufficient to finance improvements to upgrade the system. Early studies show that transferable-rights systems lead to prices high enough to generate a profit to senior-rights owners and also to generate the surplus funds needed to construct the required infrastructure. When in place, the infrastructure would provide a substitute source for the loss of groundwater resources.

Implications of Evolving Water Markets on California's Drainage and Water-Quality Problems

The drainage management options discussed earlier have a common requirement for investment in technical change or resource reallocation. The San Joaquin Valley Drainage Program (SJVDP) final plan (1990) estimates costs of $42 million per annum for 50 years. With the changes in public priorities and the extreme pressures on government expenditures, it is unlikely that public funding of this magnitude can be expected. The political climate, as reflected in recently proposed legislation (U.S. Senate, 1992), favors reduction of water allocations to Federal projects and presumably, to crop acreage associated with that water.

Given the dominance of cotton in the WSJV and the level of Federal price supports for cotton, substantial Federal payments to maintain productivity based on national economic benefits would be hard to justify politically. In short, the prospect for large amounts of Federal or State funds for maintenance of threatened areas is dim and rapidly growing dimmer.

A realistic assessment of future changes must look to changes in the pricing structure and institutions to provide incentives that contain a substantial degree of self-financing and provide internal incentives for a solution to the drainage problem. The most promising new water institution is the current emergence of water markets in California and other parts of the West.

The management options listed above for control of salinity have properties that suggest that there is no "magic bullet" solution to the problem. All the suggestions so far contain steeply increasing marginal-implementation costs for technical solutions, and regional and political constraints on institutional-solution methods. These characteristics suggest that the overall solution of the California drainage problem will not be achieved by any single approach, but rather by marginal adjustments using many approaches. There are, however, two key factors that will determine the practicality of any set of solutions: money and motivation. The introduction of water markets will compel both of these forces to engender change in existing allocations and technologies by encouraging a higher opportunity cost for water in agriculture than currently prevails. The higher opportunity cost will provide funds and motivation for

conservation, and the ability to move water to alternative uses without having political disputes over the transfer of assets. If there is an efficiency gain to be realized from a change in water allocation, then this will be realized in the form of a price differential between regions and sectors and consequent gains from trade of the water.

These points have long been discussed by economists, but the 1991 Drought Water Bank in California emphasized the practicality of this major institutional change. Over the past 15 years, suggestions by economists and others that a water market would help to rationalize the wide range of prices and allocations was, until recently, greeted with disbelief by the California water industry and political commentators. The idea was dismissed as purely academic, since everyone knew that, "if agriculture offered water for sale, the urban regions would buy everything offered and dry up agriculture." One influential government official stated in a recent speech that "water is too valuable to be allocated by market mechanisms." In short, the prevailing view was that the urban demand for California water was high priced and very inelastic.

Perceptions of the water supply function from irrigated agriculture were equally extreme. Many water-industry experts concluded that "farmers won't sell water at any reasonable price." Often the specter of another Owens Valley was invoked, conjuring up images of a rapacious urban sector creating a dust bowl in the Central Valley. Other commentators cited the experience of the most serious previous California drought, in 1977, when the U.S. Bureau of Reclamation (USBR) instituted a water bank that received a supply in the range of only 40,000 acre-feet. What was notable about the USBR's 1977 bank was that it offered a supply price that was so low that it barely covered the opportunity cost of the water for low-valued crops. Again, the supply function was described as completely inelastic after a small amount of "surplus" water was sold.

The 1991 water bank proved that both of these perceptions were completely wrong. The water supply response by farmers to the offered price of $125 per acre-foot exceeded all expectations and totaled 821,000 acre-feet. Since all of the purchased water was located north of the Sacramento–San Joaquin River Delta and had to be conveyed across the eastern part of the Delta, some carriage water was needed to maintain the hydrologic barrier against salt-water intrusion. A standard figure used to calculate the carriage water and other conveyance losses is 30 percent of the volume conveyed. With the purchase of 821,000 acre-feet from farmers, the effective net quantity for sale was 575,000 acre-feet.

The demand for purchased water came predominantly for urban use in the San Francisco Bay area and the Los Angeles basin, which purchased 91,750 acre-feet and 215,600 acre-feet, respectively. These represented 16 percent and 37.5 percent of the effective water-bank supply. However, irrigated agriculture in southern California purchased 82,400 acre-feet, which was 14.3 percent of the supply. The notable feature of the 1991 bank was that the demand for purchased water did not use up all of the available supply; 32 percent (185,000 acre-feet) of the available water went unsold and remained stored behind Oroville Dam.

There are several reasons why so much water-bank supply remained unsold in the fifth year of the drought. The overall effect is that the demand for purchased water was much more

elastic than supposed. Given the initial purchase price of $125 per acre-foot, carriage losses, and a small transaction cost, the cost of water to the purchasers at the Delta was $175 per acre-foot. When the energy costs of transporting the water to users in the south are added, the cost to users in southern agricultural and urban areas was $245 per acre-foot or higher. Only high-value fruit, nut, and vegetable crops can justify this water cost. In addition, urban areas found that some forms of conservation that could be implemented for costs of approximately $300 per acre-foot conserved were competitive with the price of water purchased from the water bank. This is not to minimize the effects of mandatory rationing programs in urban areas and the unusually heavy rains in March 1991 that partially replenished many coastal reservoirs. However, since water users estimated their "critical needs" at 498,000 acre feet on April 1, 1991, they bought less water in 1991 than they had projected in April that they would need. The result is that the aggregate demand for purchased water is more price elastic than previously supposed.

At about $5 per acre-foot, the transaction costs of the 1991 water bank were much lower than prior estimates. Much of the low transaction costs may be due to the emergency nature of the bank, which temporarily removed some of the basis for legal and environmental restrictions. Given the amount of water moved and the rapid establishment of the bank, the number of adverse environmental outcomes was remarkably low.

As of this writing, the 1992 Drought Water Bank is purchasing water. With a better winter rainfall and the carryover from previous bank purchases, the estimated demand for 100,000 acre-feet of purchased water is much lower than in 1991. Contracts for this quantity have been negotiated at a price of approximately $50 per acre-foot. This water supply was achieved without paying farmers to fallow irrigated cropland and shows, on two observations, a relatively elastic supply function. In short, water markets work.

Drainage in the San Joaquin Valley was greatly reduced in 1991, but it is still too early to be able to separate natural reductions in a drought year from any changes in irrigation practices, technology, and cropping patterns. However, there were changes in irrigated farming that were a rational response to the real opportunity cost that the water bank created for water in both exporting and importing regions.

In water-exporting regions, the water came from three sources in the Sacramento and northern San Joaquin Valleys. Fallowed cropland released 50 percent of the water, while groundwater exchange and excess available storage supplied 33 and 17 percent, respectively. The groundwater exchange was used where farmers had clear surface- and ground-water rights and could use their ground water while selling their surface water. This conjunctive use suddenly provided a cash opportunity cost to ground water that it never had previously. Needless to say, the effect of groundwater extractions was carefully monitored by local agencies. This groundwater exchange has highlighted the crucial role ground water plays in moderating the effects of California droughts. In addition, it has drawn attention to the need for better knowledge of the status and use of ground water. As the conjunctive use of ground water grows, the incentives to quantify its use will increase. More precise groundwater rights will lead to more careful use of ground water, and consequently, to reduced drainage from the overuse of a water source that had previously been characterized as a "use it or lose it"

property right.

In their choice of crops to fallow, farmers indicated that: (1) they are well aware of which crops have the lowest marginal products of water, by allocating the majority of the fallowing to low-valued field and fodder crops; (2) they respond to price incentives in a cost-minimizing manner, which means that drainage-reduction policies based on drainage charges or subsidies will indeed elicit the response predicted by economic models of farmer behavior; and (3) while the results from primary empirical surveys are not yet complete, there is considerable anecdotal evidence that the higher opportunity cost of water, and the funds made available by water-bank sales, stimulated a notable increase in the adoption of agricultural water-conservation practices.

In summary, it is not an exaggeration to say that the success of the 1991 Drought Water Bank had a dramatic effect on the way water is viewed in California. Both demands and supplies are now shown to be elastic. Transaction costs of water trades under emergency conditions are low, and may be restrained under less urgent situations.

The impact of the water bank on drainage occurs as a result of its effect on the use of water supplies in well-endowed regions, and on water demand in deficit regions. The price of water in a given year is now set on the basis of its value in use, rather than on the basis of regional and political advantage. The opportunity cost that the water bank generated for water throughout California stimulated conservation and economic use, which will have beneficial effects on drainage reduction.

Conclusions

This report addresses the problem of irrigated agriculture in the San Joaquin Valley (SJV) of California, and particularly the drainage problem on the west side of the valley. The development of irrigated agriculture in this region created problems associated with salinity and drainage. A dilemma for policymakers now exists. The conflict is over agricultural development as opposed to interests and concerns about the allocation of water and its effect on other users.

In the last decade, the water-quality problem of the SJV received attention from private and public agencies that funded many studies aimed at understanding the physical nature of the problem, the economic forces influencing it, and the feasibility of various potential solutions to minimize or solve salinity and selenium problems. The various suggested solutions included physical processes, economic incentives, regulations, and institutional arrangements.

The first conclusion, based on many engineering and economic studies that evaluated the technological and economic feasibilities of technological solutions to the drainage problem, is that these solutions are far from providing adequate answers. For example, treatment of drainage water for selenium and salinity prior to its disposal in rivers or lakes could provide a solution to the problem. Unfortunately, the technological processes investigated are still

questionable, both in terms of the economic costs of meeting quality standards and in terms of reliability. As a result, technological solutions cannot be considered in many policy analyses. This leaves policymakers with a subset of policy measures that include only economic incentives and institutional changes.

A second conclusion from the physical studies is that the factors associated with the water-quality problem in the Westside SJV (WSJV) are more complicated than originally thought. Given that conclusion, the heterogeneity of the physical conditions should be taken into account in any policy aimed at addressing water-quality problems. This means that relevant policies should be differential in nature and be adjusted to local physical conditions. Conclusions drawn from adoption studies suggest also that policies should take into consideration the structural arrangement of the economy; that is, the farm's structure, the size of the farm, or whether it is a corporation or a family farm.

Given these two conclusions, a third conclusion is suggested. Policies should be comprehensive in nature. That is, a policy should not address only one sector, or only one region. In addition, policies should be defined so that they allow changes over time in response to structural changes in the various sectors involved with the water-quality problem. For example, the increased demand for quantity and quality by the urban and environmental sectors, and the ability of the agricultural sector to adjust operations by upgrading irrigation practices, should both be built into any policy. To account correctly for possible policy effects, all sectors and all "public bads" should be identified and incorporated into the analysis.

A fourth conclusion, drawn from both the physical and economic studies, is that water-quality problems are strongly related to water-quantity problems in the WSJV. Therefore, policies should be designed to account for both quantity and quality aspects. The drought in California, which began in 1987 and remained until 1994, provides a "national laboratory experiment" that demonstrates the likely effects of reducing the availability of surface-water supplies to the agricultural sector in the SJV by up to 75 percent of normal. As indicated in Zilberman et al. (1992a), the amount of drainage water produced and disposed of in the environment was reduced during this period. On the other hand, an intensive use of ground water has also been documented in some regions. Since groundwater sources (with relatively high salt concentrations) for amending surface supplies are not available in all locations, a policy that reduces surface-water supplies may be effective in some locations, but may worsen the water-quality problem in other regions. In the latter case, saline water from marginal ground sources will add salts to the soil and to the environment through drainage disposal.

Finally, several studies indicated the importance of recognizing the relative efficiency of prices versus quotas and standards in providing a desirable policy result. Several studies indicate that in the case of the SJV, water is viewed by agricultural users as a quantity-rationed, fixed input. That is, policies to conserve water or reduce drainage that restrict water quotas to the end user will be more effective than those that increase water prices. Empirical evidence from the case-study reports by Wichelns (1991a,b) indicates that farmers respond to increased block-rate water prices. Although the evidence from this case study is coupled with

the drought effect, it is clear that block-rate prices differ from flat prices, and therefore should be investigated further as a potential policy measure.

Although not fully documented in this report, water institutions play a major role in shaping policies in the water quantity and quality arena in the SJV. Water rights, supply contracts for water quantity, water prices, and other policy-related instruments are heavily institutionalized. This creates a difficult environment for policymakers, who probably need to consider many existing institutions in addition to the policy measures they want to apply. Therefore, any policy under consideration should also account for the specific institutions that may affect its implementation.

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